International Journal of Mechanical and Production Engineering Research and Development (IJMPERD)
ISSN(P): 2249-6890; ISSN(E): 224209-8001
Vol. 5, Issue 4, Aug 2015, 25-32

EFFECT OF QUENCHING PARAMETERS ON MATERIAL CHARACTERISTICS OF SPECIMEN- AN OVERVIEW

DHIRAJ BHIKA CHAUDHARI[1], RAGHUNATH YADAV PATIL[2] & ATUL SHIVAJI CHAUDHARI[3]

[1]Student, Department of Mechanical Engineering, SGDCOE, North Maharashtra University, Jalgaon, Maharashtra, India

[2]Assistant Professor, Department of Mechanical Engineering, SGDCOE, North Maharashtra University, Jalgaon, Maharashtra, India

[3]Assistant Professor, Department of Mechanical Engineering, Government Polytechnic, North Maharashtra University, Jalgaon, Maharashtra, India

ABSTRACT

In metallurgical industries, one the most important process is the quenching of metals which consists of raising steel temperature until austenitizing temperature and cooling rapidly to avoid undesirable internal microstructure as well as to ensure uniform mechanical properties. Numerous variables in the quenching process alone govern the ability of a part to meet distortion requirements among which Selection of Quenching media, Quench tank design, Quench agitation system, Bath temperature plays an important role which has been discussed in this article.

Water due to too fast cooling produce more amount of martensite which results in hardened part. Oil due its phase transformation during quenching causes a variation in heat transfer rates hence leading to distortion. Air/gas does not have this problem and it has proven itself as environment friendly. In quench tank design draft tube impellers and directional flow baffles with improved structure gives better results. Use of quench agitation system improves the uniformity of cooling due to creation of turbulence in quench zone. . Increase in bath temperature decreases cooling rates and vice-versa.

The use of CFD (Computational Fluid Dynamics) has proven itself as a powerful engineering analysis tool to reduce distortion, improve yield and to improve "first-time" quality. Due to use of CFD simulation tool fatigue caused to heat treat engineer has been greatly reduced and hence there is no necessity of experimental investigation for the improvement of existing quench system. In this review paper emphasis has been given to focus on various parameters which affect the uniformity of quenching process and use of CFD as a powerful tool to optimise the parameters so as to get better results.

KEYWORDS: Quench Tank, Flow Rate, Cracking and Distortion, CFD Simulation

INTRODUCTION

Quenching

Quenching is the major method used to harden components in heat treatment [1]. Quenching is mostly applicable to steels where the aim is to convert the soft high temperature austenitic structure to hard martensite. Austenization or solution treating temperature may ranges from 780°C for low carbon steels to as high as 1250°C for high alloy tool steels. To achieve martensite structure, the cooling has to be fast enough to prevent the formation of other phases like pearlite and bainite. Marten site is supersaturated solid solution in alpha iron with tetragonal body centred structure. Martensite is very hard and brittle which has a “needle like” structure.

Quenching, as one of the most important processes of heat treatment, can improve the performance of various metallic alloys greatly, but an important side effect of quenching is the formation of thermal and transformational stresses that cause

Changes in size and shape that may result in cracks [3]. Therefore, it becomes technical challenge of quenching for every heat treat engineer to select the quenchant medium and process that will minimize the various stresses that develop within the part to reduce cracking and distortion while at the same time providing heat transfer rates sufficient to yield the desired as-quenched properties such as hardness [4].

Excessive distortion or even fracture is one of the biggest problems associated with quenching processes, which not only increases the cost of the production but may also directly impair the quality of the heat treated components [2]. Traditional methodology of experimental test has some limitations including significant expense and difficulty of extending accumulated experience to applications other than those from which the data was derived. Especially with the evolution of high-speed digital computers, mathematical modeling and computer simulation has developed rapidly in recent history. Large scale and sophisticated models can now be analyzed routinely only because of rapid development of various numerical analysis software and the speed of computer hardware. Controlling the volumetric fraction of desired phases such as bainite or mostly martensite, morphology of the microstructure, and distortion of the components, is the ultimate goal of the heat treaters in quenching practice. However, the target is rather hard to achieve, due to the complexity of the process and the mechanisms of heat transfer, mechanics and microstructural evolution associated with the process [2].

DISCUSSIONS

Quenching Medium

Quenching medium selection depends on the harden ability of particular alloy, the section thickness and shape involved, and the cooling rate needed to achieve desired microstructure. Hot metal parts are quenched using air, water, oil, or liquid polymers to obtain certain hardness and mechanical properties requirements [5]. Here emphasis has been given on effects of some important quenchants used in industry they are:

Air/Gas

Conventionally, water, oil or a mixture of water and a polymer are used for quenching. Water is generally too fast for most applications and will result in cracking of steel. Oil is a good quenchant, but has two significant problems. When the part first enters the oil, it starts boiling forming film around part surface and hence cooling is slow, when the film breaks down cooling speed increases. Unfortunately this happens at different times on different areas of the part leading to distortion. Second, it is not very environmentally friendly and before further processing it requires washing of parts creating a waste disposal problem. Although the water/polymer mixture has some advantages over oil, the parts still have to be washed after quenching and dried to prevent rusting.

Gas overcomes these problems. Most of the gases used are very environmentally friendly and there is no waste disposal problem. The gas does not change phase during the quenching process so the heat transfer coefficient is constant minimizing distortion.

Argon and Nitrogen

The use of argon is normally restricted to those tool steels that are sensitive to nitriding. Nitrogen at pressures up to 10 bar is quite adequate for many low alloy steels, particularly in small section sizes, e.g. 20mm diameter 16MnCr5. However, it cannot achieve the speed required for typical automotive gears in most of the common carburising steels. At 20 bar it is possible to quench a 30mm diameter bar, but for larger parts something more is needed.

Helium

It is technically feasible to use helium. 20 bar helium can quench a 40 mm diameter bar of 16MnCr5. However, helium is a rare gas, hence expensive. It is possible to recycle helium, but even the cheapest recycled helium costs ten times more than nitrogen to achieve the same quenching

Following figure illustrates the relative quenching efficiency of various gases.

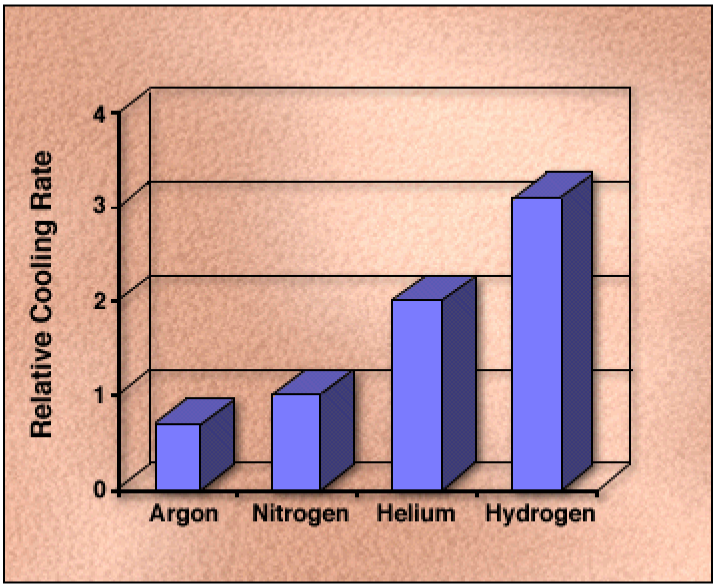

Figure 1: The Relative Quenching Efficiency of Various Gases

Water

It is probably the most widely used as it simple and effective, it cools at the rate of 982°C per second. It tends, however, to form bubbles on the surface of the metal being quenched and causes soft spots, so a brine solution is often used to prevent this trouble. Fast cooling rate achieved by water results in more amount of matensite formation and results in better hardness value. Ali RafaAltaweel , Majid Tolouei-Rad in their article named “Effect of Quenching Media, Specimen Size And Shape On The Hardenability of AISI 4140 Steel” published in Emirates Journal for Engineering Research, 19 (2), 33-39 (2014) studied the effect of water, air and compressed air as quenchent on the hardenabilty of AISI 4140 Steel.

In this study they have experienced that water as a quenchent forms more martensite other than air and compressed air and hence gives more hardened steel than other two.

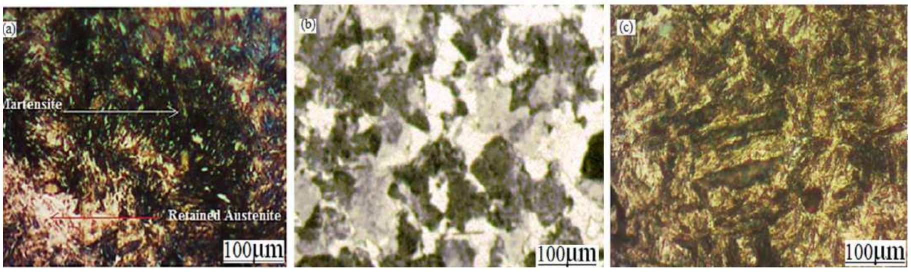

Figure 2: An Optical Metallographic Examination of Small Square Samples Quenched in Water, (B) Air, and (C) Compressed Air

Figure 3 shows the optical metallographic photographs of AISI 4140 steel specimen in which percentage of martensite is greater than other two mediums.

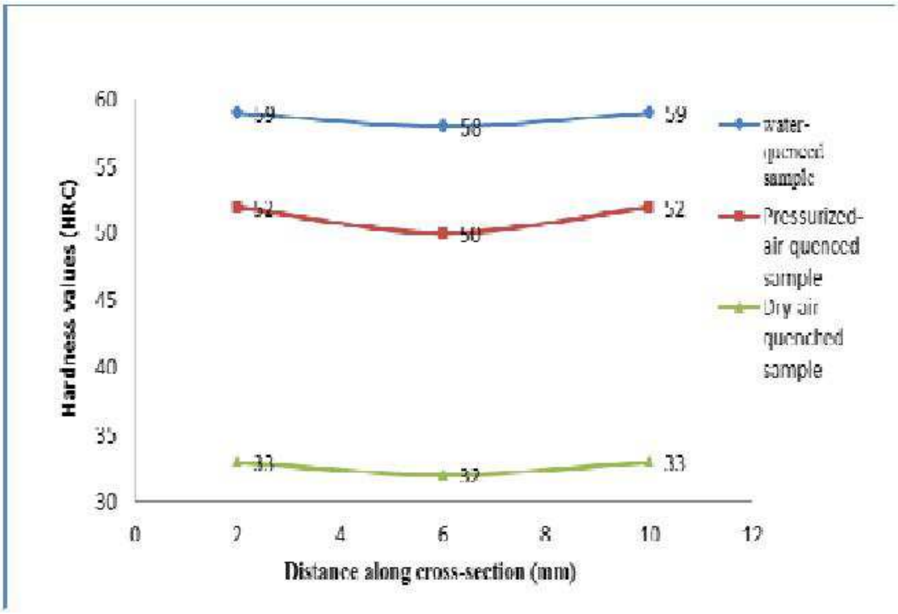

Figure 3: Hardness Values along the Cross-Section for the Small Square Specimens

Figure 3 gives the hardness values along the cross-section for the small square specimens Hardness value of specimen is greater when quenched in water.

Oil

Many components use oil quenching to achieve consistent and repeatable mechanical and metallurgical properties and predictable distortion patterns [6]. Oil quenching is so popular due to its excellent performance results and it gives stability over a broad range of operating conditions. Oil quenching facilitates hardening of steel with controlled heat transfer during quenching, and enhances wetting of steel during quenching to minimize the formation of undesirable microstructures which may lead to increased distortion and cracking. While choosing oil as quenchant one should consider following key points associated with it.

- Economics/cost (initial investment, maintenance, upkeep, life)
- Performance (cooling rate/quench severity)
- Minimization of distortion (quench system)

- Variability (controllable cooling rates)
- Environnemental concerns (recycling, waste disposal, etc.) [6]

Quench Tank Design

Actually the design of tank depends on many components used in the quench tank however some important and key components of tank are – tank body, overflow weir, agitator pump, impeller, draft tube, bend pipe, flow directional baffles. Impellers can be used with or without draft tubes. Overflow weir is used to control discharge or flow rate of quenchant in the tank, agitator is used to generate turbulence in the tank so as to improve the flow patterns of quenchant in order to give more uniform cooling and improved heat transfer rate. In open impeller mixers there is no use of draft tubes for flow directing and hence cooling cannot be as uniform as we get from draft tube impellers and hence results in variable heat transfer rate which causes cracking and distortion. According to Nailu Chen , Bo Liao , Jiansheng Pan , Qiang Li , Changyin Gao the effect of flow baffles is to redirect the flow and to remove great mass of the swirl from the impeller. The uniformity of flow rate gradually increases as the structures and position of the flow baffles are adjusted. Therefore, by improving the structures and positions of the flow baffle in the draft-tube effectively, the uniformity of flow rates in the quench tank will be increased significantly (figure 4 and figure 5).

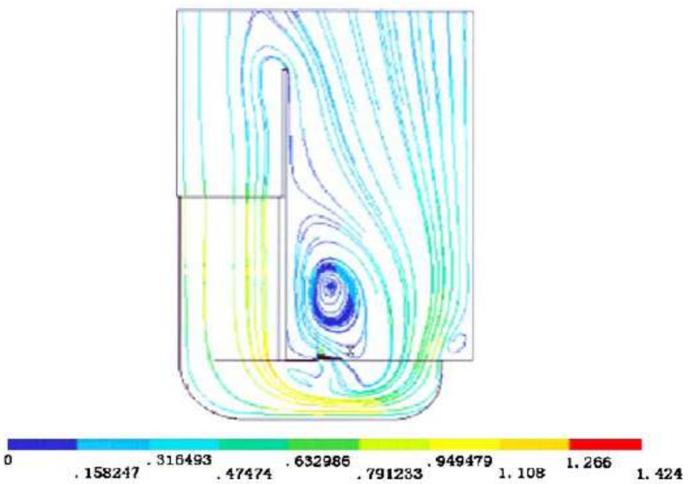

Figure 4: The Flow Rate Distribution in the X–Z Plane of Y=250 Mm without Flow Baffles at N=371 Rpm [13]

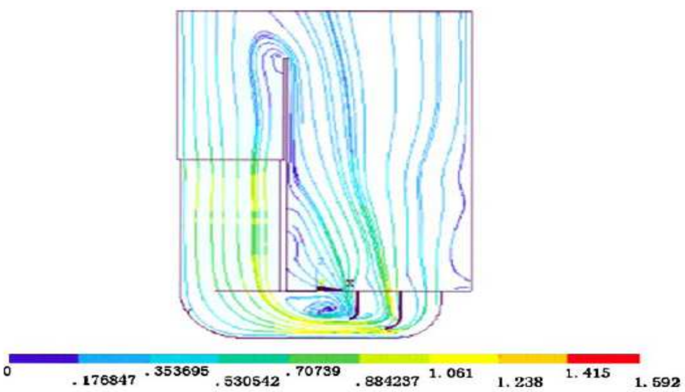

Figure 5: The Flow Rate Distribution in the X–Z Plane of Y=250 Mm with Flow Baffles at N=371 Rpm [13]

Quench Agitation System

To reduce formation of undesirable thermal gradients and internal microstructures during quenching cooling rate should be optimize. In this regard quench tank agitation system plays an important role. Quench tank agitation can be provided by various methods including the recirculation pump, submerged spray, impeller stirrer, ultrasonic, and actual movement of the part itself, etc. Among these agitation methods, the most common and cost-effective one is an impeller mixer [7].

Agitation helps to increase heat transfer rates in three ways:

- Due to agitation the liquid moves past a hot surface faster and with enhanced volumetric flow rate due to which conditions of liquid vaporization during quenching minimizes.
- In the convective cooling stage of quenching due to forced convection significantly greater rates of cooling achieved as compared to unagitated system.
- Due to agitation it is possible to control the cooling rate of the parts which can be achieved by maintaining temperature uniformity throughout the bath.

Effects of agitation on the phases of cooling of typical quench oil can be illustrated by following figures.

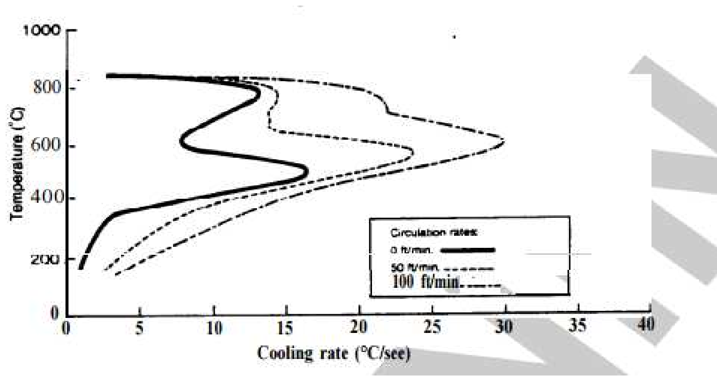

Figure 6: A at Bath Temperature 110 ^{O}f

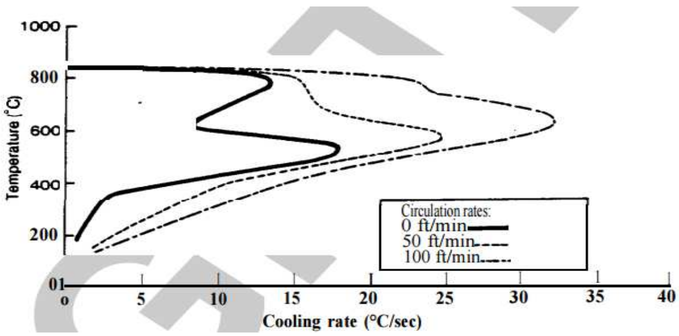

Figure 6: B at Bath Temperature 150 ^{o}F

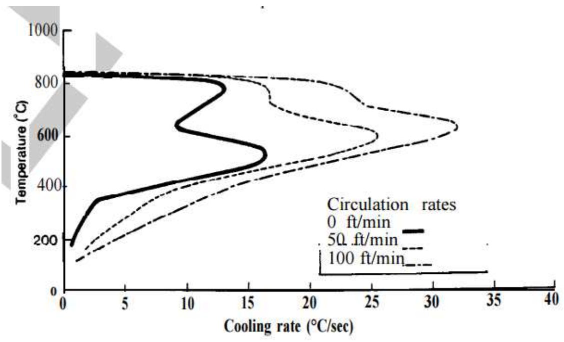

Figure 7: C at Bath Temperature 190 ^{O}f

Figure 6 Effects of agitation on the phases of cooling of a typical quench oil [6]

The results shows that

- Increasing agitation rates decrease A- stage cooling time.
- Increasing agitation rates increase B-stage cooling rates and decrease the total time to cool to the martensitic transition temperature for most steels.
- Increasing agitation rates increase C-stage cooling rates.

Bath Temperature

Control of bath temperature, or temperature rise, is also important factor for quench process control. Increasing bath temperature will decrease cooling rates. Conversely, decreasing bath temperature will increase cooling rates

CONCLUDING REMARKS

- As quenching is the important technique used in most of metallurgical industries, it is must for every heat treat engineer to understand the effect of various parameters of quenching on the mechanical properties of object to be quenched.
- As successful quenching technique depends on numerous variables, among them selection of quenchant, quench tank design, quench agitation system, bath temperature plays an important role.
- Mainly air or gas (like argon, nitrogen, helium, hydrogen,) water and oil is used as quenchent in any quenching system but polymers like UCON quenchants are also used in combination with water or alone Water has too fast cooling rates hence possibility of cracking of steel is more, also it forms more martensite structure hence more hardened part can be obtained. Oil is good quenchant but it is having waste disposal problems due to its chemical properties which make it non- environment friendly. Gas does not have these problems due to its property of retaining uniform phase during quenching which results in constant heat transfer coefficient hence minimizing distortion.
- Quench tank design depends on many components of system like draft tube impeller, structural aspects of flow directing baffles and many more. Use of draft tube impellers will results in directional fluid flow around a part surface being quenched. Significant improvement in the structure of flow directing baffles results in improved flow which minimizes formation of swirl in mass flow of quenchant.
- Quench agitation system is used to create turbulence in the quench zone which results in breakdown of vapour

film formed around the surface of part being quenched and increases the heat transfer rate hence results in better cooling. Due to use of agitation in quench system possibility of cracking and distortion minimizes and we get desirable internal microstructures. Increase in bath temperature decreases cooling rates and vice-versa.

- CFD has proven itself as a powerful analysis tool for the simulation of quench system which reduces labour cost, equipment cost and time involved in the trial and error method of experimental investigation for the improvement of the existing quench system.

REFERENCES

1. Ericsson, T, (1991) "Principles of Heat Treating of Steels", Metals Handbook, 10th ed. Vol. 4, ASM International, Materials Park, Ohio, pp. 3-32.
2. Chen, Xiao Leo, (1998), "Computer simulation of the thermal-mechanics of steel quenching", Scholar Archive. Paper 2600.
3. Totten, G., et.al, (1997), Steel Heat Treatment Handbook. Marcel Dekker, Inc. p. 157.
4. Chaves, J.C., (2001) The Effect of Surface Condition and High Temperature Oxidation on Quenching Performance of 4140 Steel in Mineral Oil, in Manufacturing Engineering., Worcester Polytechnic Institute: Worcester. p. 8, 9.29.
5. Aulus R. Romao Bineli et.al (2010),” Simulation to Analyze Two Models of Agitation System in Quench Process” 20th European Symposium on Computer Aided Process Engineering,pp.1-6.
6. Daniel H. Herring (2010 “Oil Quenching “,”The Heat Treat Doctor” The HERRING GROUP, Inc. pp. 1-24.
7. Nailu Chen et.al, (2006) “Improvement of the flow rate distribution in quench tank by measurement and computer simulation” Materials Letters (60)1659–1664.
8. Totten G.E.et al, (1993).” Handbook of quenchants and quenching technology” [M]. Ohio: ASM International, 339−411.
9. Totten G E.et. al, (1996),”Quenching fundamentals: Effect of agitation” [J]. Adv Mater Process, (149) 73−76.
10. Versteeg H. K., Malalasekera W. (1996) “An introduction to computational fluid dynamics: The finite volume method “[M]. New Jersey: Prentice Hall, pp. 45−65.
11. Canale L C F, Totten G E., (2005) Quenching technology: A selected overview of current state-of-the-art [J]. Materials Research, 8(4): 461−467.
12. .G.E. Totten, K.S. Lally, (1992) “Proper agitation dictates quench success”, Heat Treating, (9)12–17.
13. Chen N L et.al. (2006),”Improvement of the flow rate distribution in quench tank by measurement and computer simulation “[J]. Mater Lett. , 60 (13−14): 1659−1664.